Benign Bone Tumors

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Abstract

Benign bone lesions are a broad category that demonstrates a spectrum of activities from latent to aggressive. Differentiating the various tumors is important in order to properly determine necessary intervention. This chapter focuses on the presentation, imaging, diagnostic features, and treatment of the most common benign bone tumors in order to help guide diagnosis and management.

Keywords

Incidental · Latent · Observation · Aggressive · Curettage · Adjuvant

1 Introduction

The true incidence of primary bone lesions is unknown as many are asymptomatic and go undetected unless incidentally discovered. Such lesions can arise due to developmental aberrancies, reactive changes, or localized neoplastic processes. Activity lies on a spectrum from latent to aggressive. All, however, are categorized as benign because their action for the most part is local.

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T. D. Peabody and S. Attar (eds.), *Orthopaedic Oncology*,
Cancer Treatment and Research 162, DOI: 10.1007/978-3-319-07323-1_3,

More common in younger individuals, benign bone lesions have varied presentations and varied treatments, ranging from mere observation to en bloc resection. While many benign bone lesions exist, this chapter will focus on the most common. Characteristic features will be described to assist diagnosis and guide appropriate treatment. On a whole, bone tumors are not common. Any uncertainty with diagnosis or management should prompt the consideration to refer to an orthopedic oncologist.

2 Clinical Presentation

Review of demographic information and a detailed history can help to form a working differential diagnosis. It is important to have the patient characterize the location of symptoms and detail events leading up to the evaluation. A clear understanding of symptom onset, duration, intensity, change over time, alleviating/exacerbating factors, attempted interventions, associated constitutional symptoms, and any significant past history such as infection or metabolic problem, is imperative. Surgical and family history is also quite valuable. Specific inquiry should ask about related trauma, pain at rest or at night, and patient's perception of symptom progression. Physical exam localizes the symptomatic area, which is inspected for visible swelling and overlying skin changes. Palpation assesses tenderness, presence of a mass, and pulsations. Nearby joints should be ranged and the neurovascular status of the involved area cataloged. A broader inspection should look for associated deformity, leg-length discrepancy, skin café-au-lait spots, and lymph node swelling.

The physician has a clinical sense after taking a history. If symptoms seem more indicative of another process such as tendon inflammation, if symptoms developed acutely after trauma, or if symptoms are resolving, a latent lesion, perhaps found incidentally, is suspected. Increasing pain localized to a bone or joint, a palpable mass growing in size, pain at rest or at night, or associated weight loss or night sweats—these signs and symptoms raise concern that an active or malignant process may be taking place.

3 Imaging

Radiographs are the next step in management. They are economical, accessible, and provide a wealth of information (Fig. 1). Orthogonal views should be obtained. Additional views are helpful in complex areas such as the ribs, scapula, spine, pelvis, and foot. In addition to location and size, radiographs give an impression of the host bone response to the tumor. The zone of transition from tumor to normal bone characterizes the margin, which reflects the growth rate. A narrow transition is often radio-dense and well-defined—features of a slow process. Surrounding bone has had a chance to react. In a wide transition, it is difficult to delineate the end of tumor and the beginning of normal bone. It reflects a more

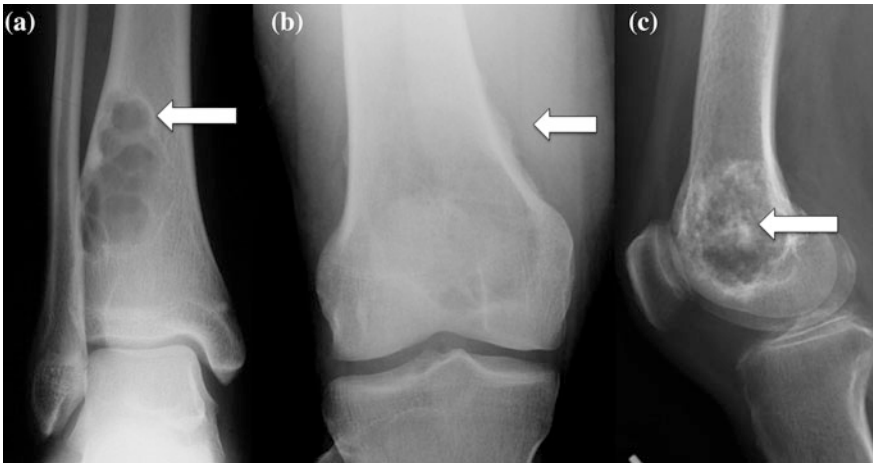

Fig. 1 Host bone response to tumor: zone of transition (**a**) and periosteal reaction (**b**). Intralesional matrix mineralization of a benign bone tumor (**c**)

aggressive process that is overwhelming native bone. Bone destruction is seen on radiographs, which represents at least 30–50 % loss of mineral [1]. Periosteal reaction depicts biologic behavior of the tumor. Benign reaction is often unilaminar while more aggressive lesions have a multilaminar appearance with triangular interfaces where the periosteum is lifted away at the edges from host bone, a phenomenon known as Codman's Triangle [2]. Intralesional mineralization is another feature assessed on radiographs. Its presence offers a clue to the histologic composition of the tumor. Osteoid appears as a fluffy radiodensity; cartilage as stippled or arc calcifications; fibrous as a hazy radiodensity described as "ground glass" [2]. Patients should be asked about any prior imaging of the same region. Comparison gives some perspective on lesion occurrence and progression. Enneking has described features of benign lesions on radiographs. They are characterized as latent, active, or aggressive [3]. Latent appearing lesions do not need further imaging studies. Active or aggressive lesions do.

A computed tomography (CT) scan is indicated in tumors with aggressive features, lesions with suspected matrix mineralization (Fig. 2), and in areas of heavy anatomic overlap such as the sternum, pelvis, acetabulum, and spine. CT provides the best assessment of bony anatomy and excels at qualifying erosion, perforation, and occult fracture. It is the choice study for cortically based lesions and for the risk assessment of impending fractures.

Magnetic resonance imaging (MRI) with intravenous gadolinium adds information about soft tissue, bone marrow, and intra-articular involvement. Signal characteristics on different sequences can be used to gauge lesion composition as well as presence of hemorrhage and/or necrosis (Fig. 3). Comparison of pre and postcontrast fat-suppressed T1 images determines the enhancement of the lesion, which is an indication of its blood supply and an indirect measure of biologic

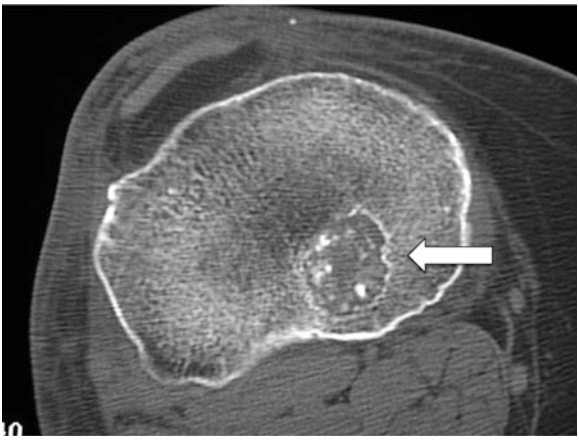

Fig. 2 Matrix mineralization on CT scan

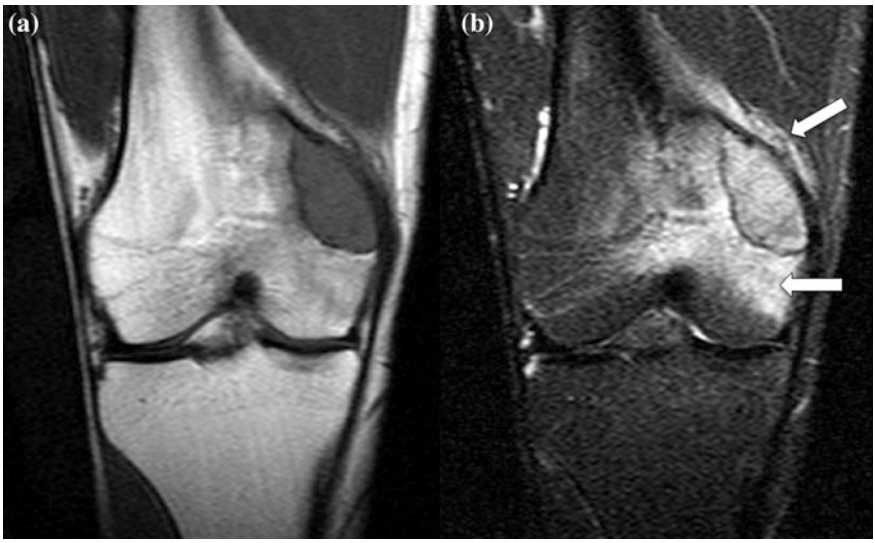

Fig. 3 MRI of a benign bone tumor of the medial femoral condyle: low T1 signal with well-defined anatomy (**a**), High T2 signal with sensitivity to soft tissue and bony edema (*arrows*) (**b**)

activity. Additional MRI sequences further characterize tumor aspects that improve diagnostic accuracy. Dynamic Enhanced MRI differentiates reactive bony edema from tumor extension into bone [4]. Quantitative Dynamic MRI best qualifies the degree of tumor necrosis, an indication of tumor growth [5, 6]. Diffusion Weighted MRI helps in the spine by distinguishing osteoporotic from pathologic vertebral compression fractures [7]. MRI Spectroscopy measures the quantity of certain metabolites in tumors, which helps with diagnosis [8].

Bone scanning with Technetium-99 m assesses osteoblast activity in the primary lesion as well as uncovers additional sites of disease in the skeleton (Fig. 4) [9]. In benign disease this represents multifocal or polyostotic disease, which can be seen with Fibrous Dysplasia, Enchondroma, and Nonossifying Fibroma.

Positron emission tomography (PET) imaging alone or combined with CT or MRI is a diagnostic measure of metabolic activity (Fig. 5). Its role in bone tumors is undetermined. The tracer Fluorodeoxyglucose (^{18}F) is preferentially taken up by cells utilizing cellular glycolysis [8] The degree of uptake, measured in Standard Uptake Values (SUV), can help distinguish benign from malignant tumors. Moreover, SUV can be used to determine lymph node involvement, guide biopsy placement, gauge treatment response, and monitor for recurrence after treatment. The average SUV uptake for benign lesions is 2.18 compared to 4.34 for malignant [10]. The addition of CT and MRI to PET is being investigated as an all-encompassing staging tool but is hampered by an unacceptable rate of false negatives [11].

Most benign bone tumors are evident after clinical evaluation and imaging. There are times, however, when the diagnosis is still unclear and the possibility of malignancy cannot be excluded. Biopsy is then necessary to guide treatment. For bone lesions, CT-guided biopsy is preferred as it allows accurate localization, identifies mineralized areas for sampling, and can be done under anesthetic titrated to patient comfort. The radiologist and orthopedic surgeon should collaborate to plan the biopsy. This avoids unnecessary contamination of normal tissues and maintains a tract that could be excised if needed. In addition, cultures should be taken at the same time as the biopsy.

4 Diagnosis

While pathognomonic findings are rare, a constellation of findings can often be used to sufficiently narrow a differential diagnosis to make treatment decisions. This section will review the characteristic findings for the most common benign tumors of bone as well as elaborate on a few of the common reactive and residual bony changes that mimic bone tumors.

5 Nonossifying Fibroma

Also called fibroxanthoma or, when smaller, fibrous cortical defect (FCD), these lesions are thought to be an abnormal development extending from the growth plate (Fig. 6). They are common, found in, approximately, 30 % of people, and most present as asymptomatic, incidental findings in the first two decades of life [12]. Pain from pathologic fracture can occur and most lesions are found in the lower extremities [13]. On radiographs, lesions are typically radiolucent, eccentric, and cortically based in the metaphysis. They often elongate with skeletal growth and eventually extend into the diaphysis. Bony trabeculae are maintained and the

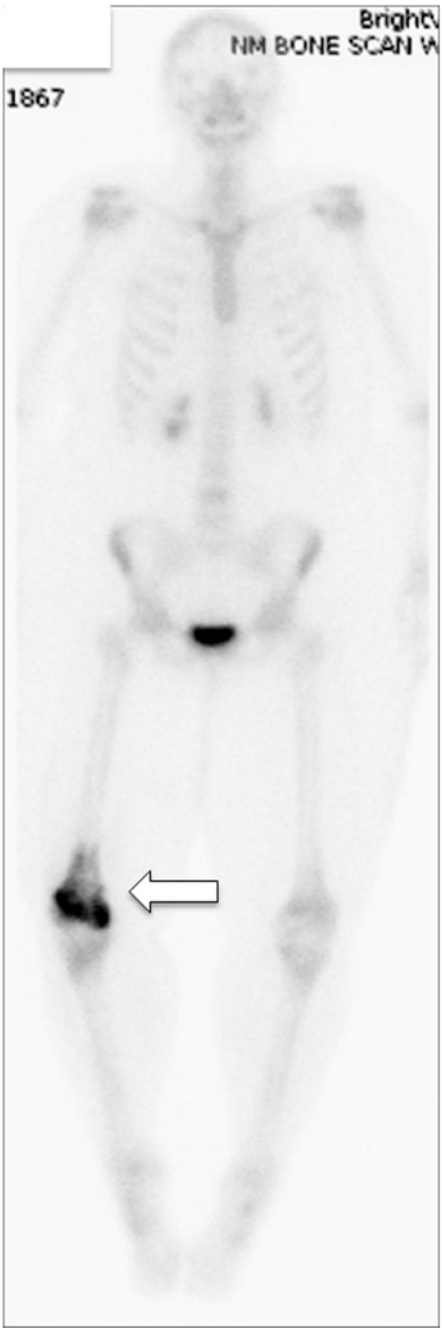

Fig. 4 Bone scan showing activity in the distal femur

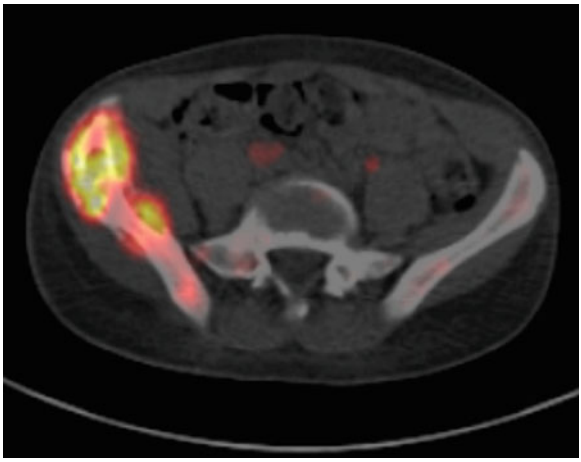

Fig. 5 PET scan with increased metabolic activity in the right ilium

zone of transition is narrow but thin. MRI demonstrates a characteristic low signal on both T1 and T2 sequences without enhancement. High signal on T2 can be seen with an associated stress fracture. Histologically, there is an appearance of fibrous bundles with a mixture of giant cells, lipid-laden macrophages, and hemosiderin with cholesterol clefts. Osteoid can be seen if there has been a recent fracture. The natural history is spontaneous resolution with skeletal maturity. An expanded sclerotic region is typically all that remains in adults [14]. Observation with serial radiographs is adequate for most lesions. The majority of pathologic fractures are treated with weight bearing or activity restrictions with or without immobilization. Twisting is often the mechanism leading to fracture and should be avoided during recovery. Treatment with curettage, grafting, and possibly internal fixation should be considered with displaced fractures, multiple fractures, large lesions at high-risk of fracture, and those that develop a secondary aneurysmal bone cyst (ABC). Recurrence is uncommon and malignant transformation is very rare. Multiple NOFs, café-au-lait skin lesions, and mental retardation characterize Jaffe-Campanacci Syndrome. These patients need to be monitored for symptomatic lesions. There is no increased risk of malignant transformation [15, 16].

6 Fibrous Dysplasia

FD is a spontaneous developmental anomaly leading to an area of fibrous tissue and nonossified bone (Fig. 7), usually diagnosed in the first three decades of life, it is commonly located in the femur, tibia, ilium, skull, and rib. Most cases present as incidental findings or as pain secondary to pathologic fracture. Eighty percent of lesions are monostotic with the remainder polyostotic [17]. Radiographs demonstrate a centered, medullary based radiolucent lesion in the metaphysis and/or diaphysis with bony expansion and loculations. Sclerotic rims are seen in the

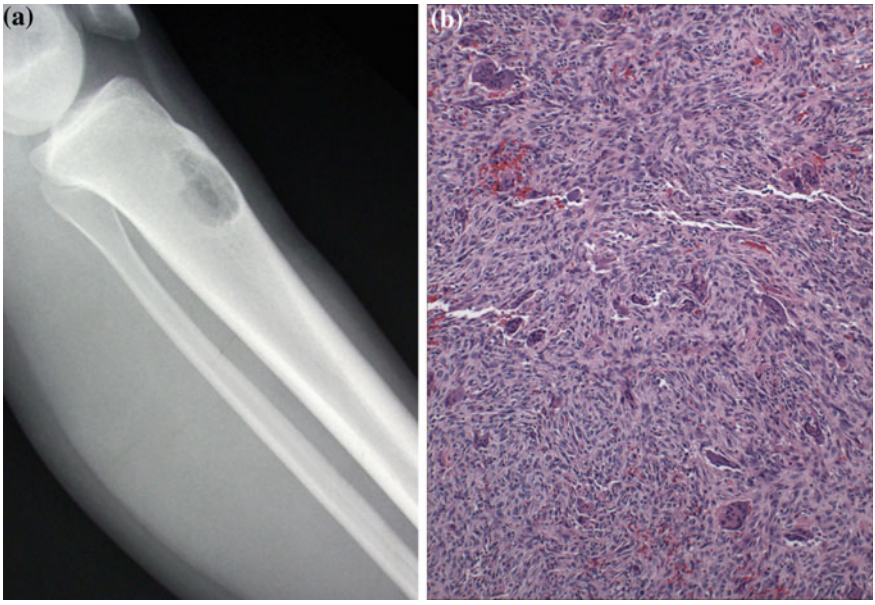

Fig. 6 Radiograph (**a**) and histology (**b**) of a Nonossifying Fibroma

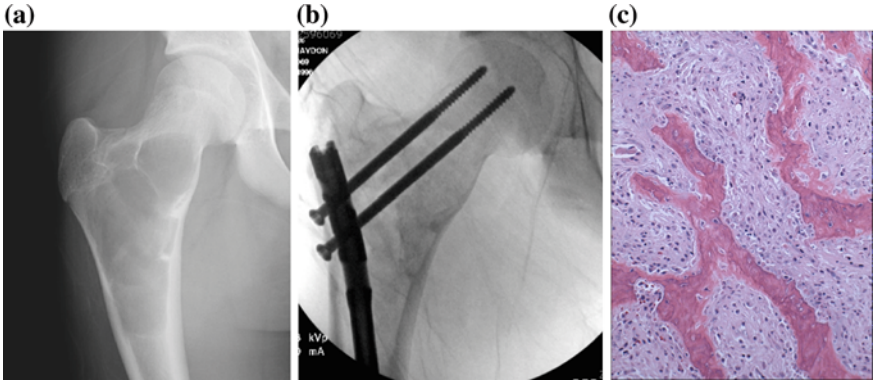

Fig. 7 Fibrous dysplasia of the right femur on radiograph (**a**), after internal fixation for impending fracture and developing varus deformity (**b**), and on histology (**c**)

proximal and distal aspects of the lesion within the medullary canal. The zone of transition is narrow and often sclerotic. Internal matrix on radiographs has a hazy central appearance described as "ground glass" with a radiolucent rim [14]. Deformity can occur through repeated stress fractures with varus alignment of the proximal femur (Shepherd Crook's Deformity) being common [18]. MRI is low on T1 and variable on T2. T2 high signal may represent bony edema secondary to

fracture. Enhancement is serpiginous. Bone scan demonstrates activity. These lesions get larger with skeletal growth and rarely resolve spontaneously. They are usually present throughout life. Histology shows fibrous tissue with islands of woven bone absent of osteoblastic rimming. Pathologists describe spicules of woven bone as having an "alphabet soup" appearance. Most are observed with serial radiographs. Nondisplaced fractures or stress responses can be treated with weight bearing or activity modification with or without immobilization. Curettage, grafting, and possible internal fixation is indicated with displaced fractures, multiple fractures, worsening deformity, impending fractures, and secondary ABC (arising out of FD). Due to the metabolic origin most lesions recur after curettage, and therefore any internal fixation should be placed with long-term intention for structural support. Any resolved areas will show patchy sclerosis on radiographs. Transformation into malignancy is rare. It is foreshadowed by increasing pain, swelling, cortical destruction, and an associated soft tissue mass [13]. Polyostotic FD usually affects one side of the body and can be associated with precocious puberty and café-au-lait spots in McCune-Albright and with soft tissue intramuscular myxomas in Mazabraud Syndrome [8, 19]. Polyostotic forms are best detected on bone scan and benefit from evaluation by an endocrinologist. Bisphosphonate or RANK ligand inhibitor therapy may be considered in adults.

7 Osteofibrous Dysplasia

OFD is a fibrous defect of unknown origin in bone (Fig. 8). It presents as painless, progressive swelling or as local tenderness when associated with pathological fracture. Most cases occur in the first decade of life and are localized to the anterior tibial cortex, rarely the fibula [13]. Radiographs demonstrate a cortically based radiolucent area with multiloculated cysts and expansile features. Internal matrix is generally mixed lytic and sclerotic. Anterior or anterolateral bowing of the tibia can be seen. MRI shows intermediate T1 and high T2 signal as well as enhancement with contrast. Bone scan is active. Histology shows a vascularized fibrous stroma with spicules of woven bone rimmed by osteoblasts. Mitoses and giant cells can be present [20, 21]. Treatment is observation. Most lesions remain static and regress with advancing age [22]. Deformity can be braced and rarely requires osteotomy. There is a low threshold to biopsy of these lesions because of the similar appearance to the low-grade epithelial malignancy adamantinoma. Adequate sample should be sent during biopsy to avoid sampling error. Curettage, grafting, and possible internal fixation can be considered for persistent pain, risk of pathologic fracture, and worsening deformity. Follow-up is life-long to assure OFD is not an indolent adamantinoma. Sudden growth, invasion of the medullary canal, and development of a soft tissue mass are indications to pursue biopsy.

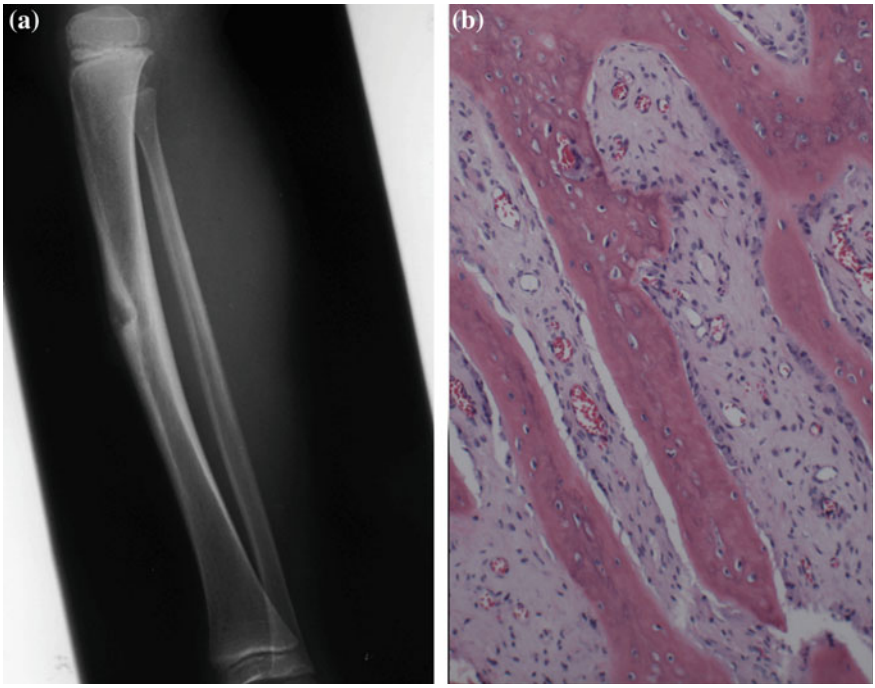

Fig. 8 Radiograph (**a**) and histology (**b**) of osteofibrous dysplasia

8 Enchondroma

EC is a rest of hyaline cartilage within the medullary canal of long bones and tubular bones of the hands and feet (Fig. 9) comprising 12–24 % of benign bone tumors, they are often painless and incidentally found [23]. EC can present with pain due to pathologic fracture. Peak incidence is in the third decade of life. Radiographs generally show a central radiolucent lesion in the metaphysis with lobular margins and a narrow zone of transition [24]. Matrix mineralization can be variable, but characteristically occurs as "rings and arcs" and is best identified on CT scan [13]. Mineralization is usually absent in the hands and feet. MRI shows uniform low signal on T1 sequence. T2 sequence has a high signal secondary to the water content of hyaline cartilage with small areas of low signal representing mineralization. There should not be MRI enhancement or bone scan activity. Histology demonstrates hyaline cartilage with sparse chondrocytes with no nuclear atypia or mitotic figures. Hand ECs look more aggressive under the microscope. Treatment consists of observation with serial radiographs. Curettage and grafting with optional internal fixation may be considered for multiple fractures, impending fracture, or painful lesions. EC should not progress or recur. Any clinical indication of increasing pain or imaging showing progressive growth, endosteal scalloping,

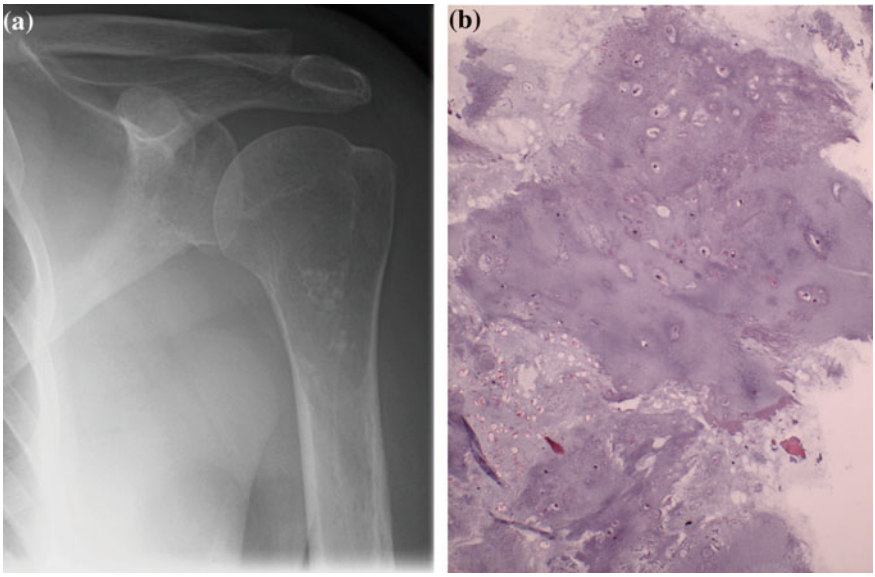

Fig. 9 Radiograph (**a**) and histology (**b**) of an enchondroma

cortical destruction, or a soft tissue mass should warrant a biopsy to assess for secondary chondrosarcoma [24]. Isolated lesions rarely transform. Larger and more proximal lesions are at greatest risk [14]. Hand ECs are exceedingly rare to transform despite their histologic appearance [13]. Noninherited conditions with multiple ECs exist. They often affect one side of the body and are at greater risk of secondary transformation, which occurs in adulthood. Ollier's Disease consists of multiple EC whereas Maffucci Syndrome is multiple EC with soft tissue hemangiomas and/or lymphangiomas. With either, there is a 20–30 % chance of malignant transformation [25]. In adulthood, these patients should be monitored with periodic chest CT and whole body bone scan. Areas with activity on bone scan are investigated further with MRI. There is a fine line between the diagnosis of EC and grade 1 chondrosarcoma. The latter is treated with intralesional curettage and grafting. More aggressive chondrosarcomas are widely excised.

9 Osteochondroma

OC or exostosis is a surface lesion of bone (Fig. 10). It is thought to be physeal cartilage displaced onto the longitudinal surface of bone. A common benign bone tumor, it is noticed as a painless mass near joints in the first two decades of life. Symptoms may be present from traumatic fracture or mass effect, as OCs grow with the patient. Affected extremities should be inspected for associated deformity and leg-length discrepancy. Lesions can occur in any bone undergoing endochondral

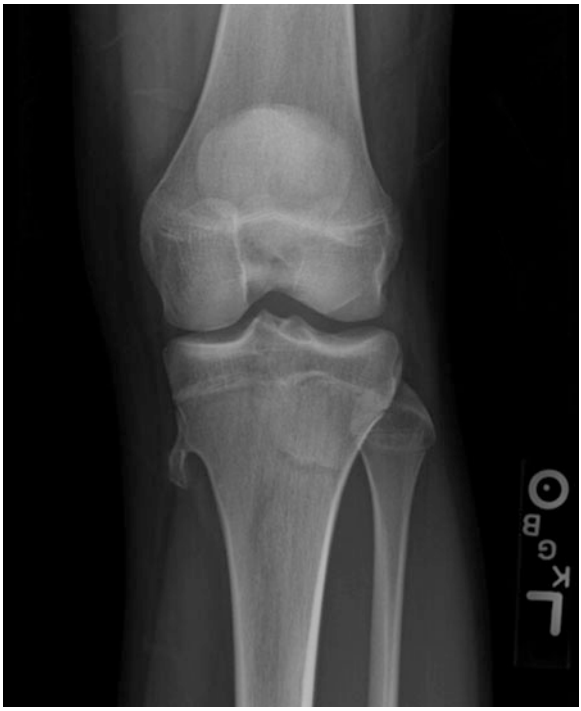

Fig. 10 Radiograph of an osteochondroma

ossification. The knee, ilium, and scapula are common locations. On radiographs, a bony growth is seen at the metaphysis aiming away from the joint. CT scan demonstrates cortical and medullary continuity between the OC and host bone. MRI shows nonspecific low T1 and high T2 signal of the surface. The top of the OC is composed of a cartilage cap connected to native bone with a pedunculated or sessile stalk. Histology shows lamellar bone connected to a hyaline cartilage cap covered by a perichondrium of dense collagen [26, 27]. Endochondral ossification is seen in the cap until skeletal maturity. Treatment consists of observation and symptom control. If symptoms persist or worsen despite medical intervention, marginal excision is considered. It is best to wait until OCs move away from the physis to avoid growth arrest after surgery. OCs stop growing at skeletal maturity. Malignant transformation of isolated OC is rare and occurs in adulthood. It is preceded by sudden growth and increasing pain. Radiographs show cortical erosion of the osseous protuberance [18, 19]. MRI is indicated to assess the cartilage cap. An irregular cap with incomplete calcification and thickness 2 cm or more is highly suspicious for secondary chondrosarcoma [28, 29]. At times, it can be difficult to distinguish adventitial bursae from a cartilage cap. Use of ultrasound or contrast MRI can help differentiate. Patients with the familial autosomal dominant condition known as multiple hereditary exostosis (MHE) have polyostotic OCs and a 5 % risk of malignant transformation. Transformation is more likely in the pelvis, scapula, and proximal femur [30]; areas the lesion can grow undetected for some time. MHE

patients need to be routinely followed with clinical exams throughout life. Symptomatic areas should be X-rayed and surveillance pelvis radiographs should be obtained every 5 years. A developmental disorder known as Trevor's Disease or Dysplasia Epiphysealis Hemimelica (DEH) is characterized by OC of the epiphysis in a single extremity [13]. These point toward the joint and are treated the same way as isolated OC with the same risk of malignant transformation.

10 Chondromyxoid Fibroma

CMF is a rare bone lesion of unknown origin that frequently presents as a palpable mass or localized swelling (Fig. 11). Pain is variable and pathologic fracture is uncommon. The majority of patients are male in the second to third decades of life [13]. Prevalent locations are the foot, pelvis, and knee. Radiographs show a well-defined radiolucent lesion that is eccentric in the metaphysis. The zone of transition is narrow with variable thickness. CT scan demonstrates lobules and a paucity of matrix mineralization. MRI signal is low on T1 and high on T2. Nodules of dense cartilage between fibromyxoid areas characterize the histology. The zonal architecture shows well-defined areas of mixed cellularity with occasional giant cells. These lesions expand and become symptomatic. Intralesional curettage and grafting with or without internal fixation is the preferred treatment. Recurrence is approximately 25 % after curettage alone [31]. En bloc excision is considered after multiple recurrences.

11 Chondroblastoma

CB is an uncommon bone tumor of unknown origin (Fig. 12). Occurrence is more frequent in males in the first two decades of life [13]. Most patients present with joint pain and restricted motion. The knee, shoulder, hip, and heel bones are typical locations. Radiographs show an epiphyseal or apophyseal radiolucent lesion with a narrow zone of transition. The thin surrounding rim may be expansile. Marked cortical destruction is associated with secondary ABC formation, which occurs in 15 % of CBs [13]. Lacelike matrix mineralization can be seen on CT, along with scalloped borders and periosteal reaction. Notable inflammation produces high signal marrow edema on T2, which surrounds the low to intermediate signal of the tumor. T1 signal is low. Bone scan is active [8]. Plump chondroblasts with giant cells are seen among calcifications spread out in a pattern described as "chickenwire" on histologic review. These lesions are progressive and increasingly painful. Treatment is intralesional with curettage and grafting with or without internal fixation. Some success has been demonstrated with radiofrequency ablation (RFA) [32]. Care must be taken with any treatment to avoid damage to nearby growth plates and articular cartilage. Recurrence depends on the type and adequacy of treatment and ranges from 5 to 20 % [33].

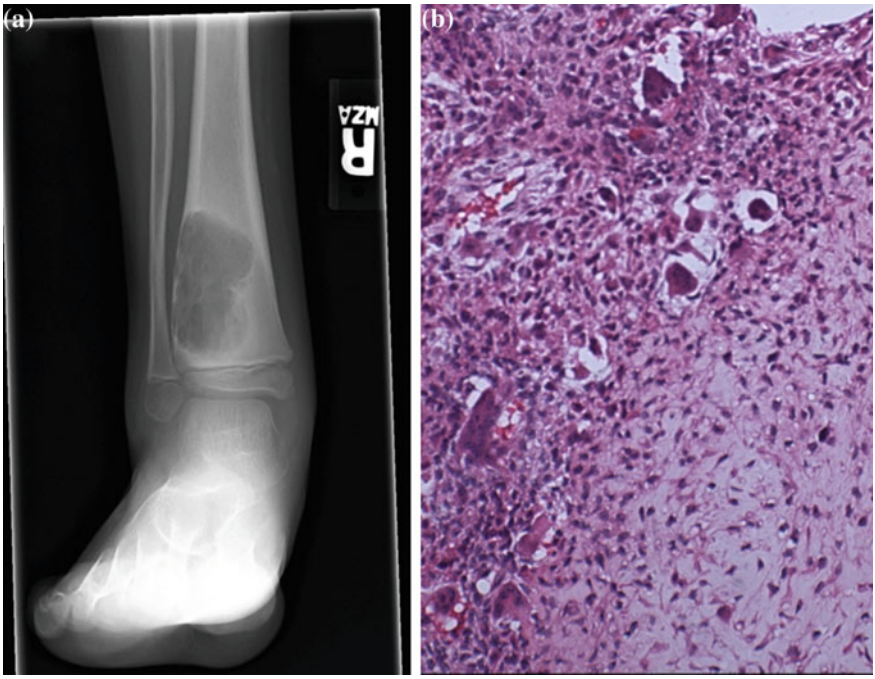

Fig. 11 Radiograph (**a**) and histology (**b**) of chondromyxoid fibroma

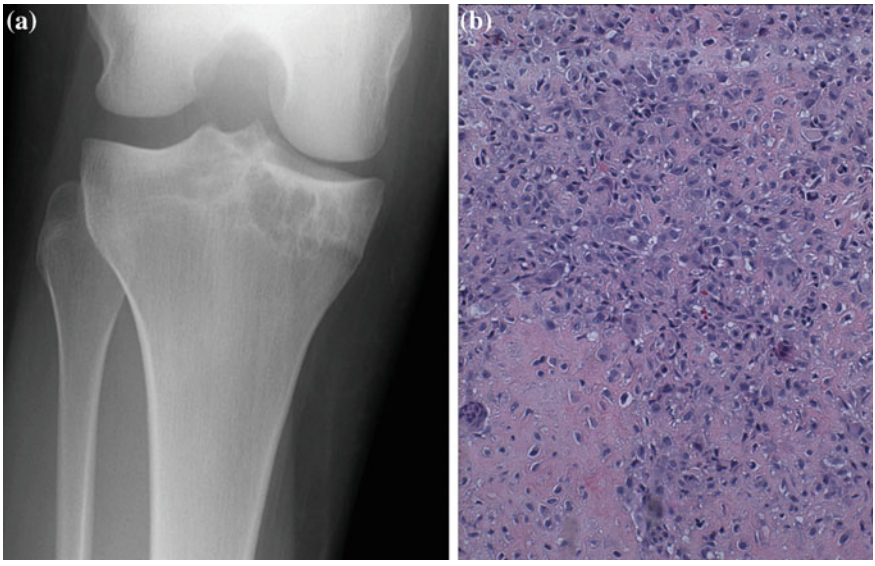

Fig. 12 Radiograph (**a**) and histology (**b**) of Chondroblastoma

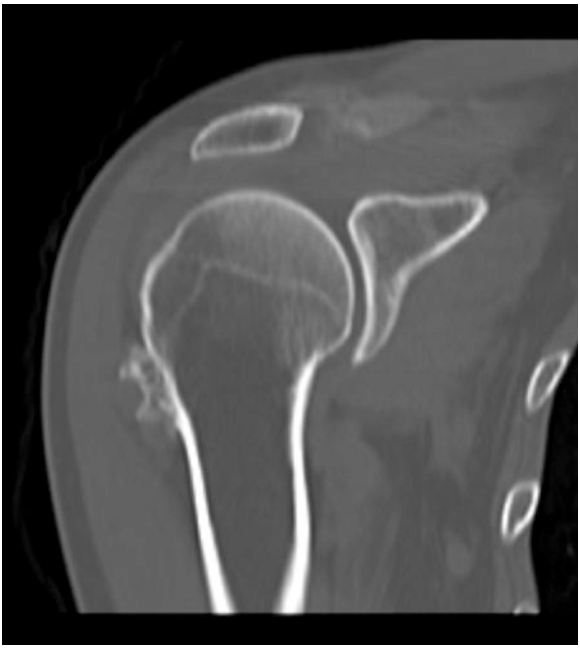

Fig. 13 CT scan of a proximal humeral periosteal chondroma

12 Periosteal Chondroma

Periosteal or juxtacortical chondroma is rare and the origin unknown (Fig. 13). Focal swelling is the most common presentation and men in the second and third decades of life are the most affected [13]. Frequent locations include the distal femur, proximal femur, proximal humerus, hands and feet. Radiographs show a lesion extending from the metaphyseal cortex pushing into soft tissue, appearing as a "soap bubble." Sclerosis is prominent between the lesion and the medullary canal and the outer metaphyseal cortex is frequently saucerized from pressure. The periosteum is lifted up and some reaction may be visible. CT scan best demonstrates the thin cortical shell and variable mineralized matrix. Signals are low T1 and high T2 on MRI [13]. The lesion does not enhance but overlying bursae may. Bone scan is cold. Bland chondrocytes in lacunae with surrounding endochondral ossification is seen on histology. Lesions may be observed, but their behavior is typically progressive. When symptomatic, intralesional curettage and grafting with or without internal fixation is performed. Recurrence is unlikely.

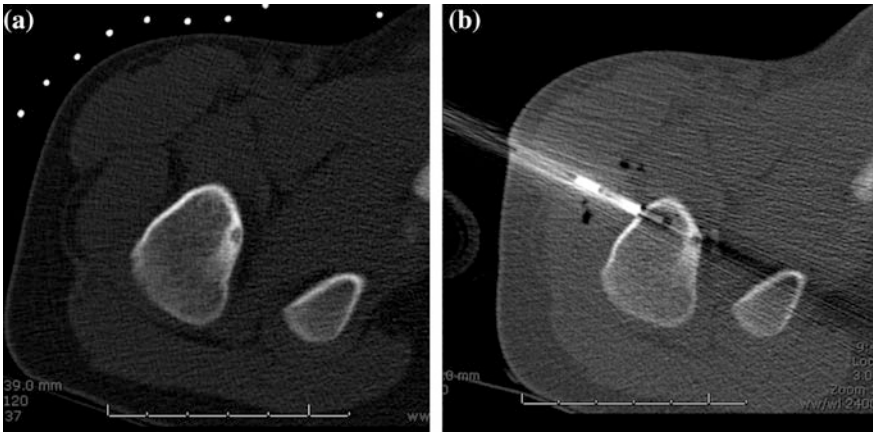

Fig. 14 Axial CT scan of an osteoid osteoma (**a**). Treatment with CT guided radiofrequency ablation (**b**)

13 Osteoid Osteoma

Osteoid osteomas comprise around 12 % of benign bone tumors [34, 35] (Fig. 14). Their cause is unknown. They characteristically present in the first three decades and occur more often in males [36]. Most patients have localized pain that worsens at night. Additional symptoms vary by location. Long bone OOs, most common in the metadiaphysis of the femur and tibia, have tenderness, swelling, and muscle atrophy [37–39]. Intra-articular lesions close to growth plates may have a joint effusion, limb overgrowth, limb deformity, abnormal gait, joint contracture, and limited range of motion [38, 40]. Twenty percent of OOs occur in the posterior elements of the spine, they present with back pain and scoliotic deformity. The curve is secondary to muscle spasm and the lesion can be found on the concave side of the curve [13]. Tumors are usually less than 1 cm and are most often cortically based, although they can be subperiosteal, intraarticular, or in cancellous bone. OOs can be hard to see on radiographs. An isolated area of reactive cortical thickening from periosteal bone formation can be seen. Close scrutiny of X-rays and a high-index of suspicion lead to further imaging with thin slice CT or bone scan. Axial CT shows a mineralized osseous nidus with a lucent halo and surrounding thick spherical or ovoid sclerosis. Bone scan shows increased activity. MRI can be misleading as intense soft tissue and bone marrow edema obscures the lesion and appears as a large mass. This can lead to a futile work-up for malignancy or infection [32, 41]. Osteoid and woven bone lined with osteoblasts and richly innervated with surrounding hypervascular connective tissue with osteoclasts is seen on histology [42]. OOs do not malignantly transform [37, 43]. Debilitating symptoms justify treatment. Pain has been linked to elevated cyclooxygenase expression and subsequent increased prostaglandin (PG) synthesis

[44, 45]. Nonsteroidal Antiinflammatory Drugs (NSAIDs) or salicylates inhibit PG synthesis and are the first-line of treatment. Patients must be screened for renal insufficiency, gastrointestinal bleeding, and stomach ulcerations before initiating treatment. Concomitant use of a medication to reduce stomach acid as well as periodic lab draws to assess anemia and renal function is recommended. It takes an average of 33 months on therapy for symptoms to resolve [46]. When NSAIDs are contraindicated or the patient/family does not want to pursue medical therapy because of progressive deformity, growth disturbance, arthritis, rigid scoliosis, or pain, percutaneous, or open techniques are employed. CT-guided excision and RFA are both effective percutaneous techniques. Excision obtains sufficient pathologic tissue for a more reliable histologic diagnosis, but creates a larger bone defect raising the risk of postoperative fracture [47]. RFA has become very popular and eliminates 80 % of lesions with one treatment, 96 % with two [48]. Pathologic diagnosis can be obtained, but it is not as reliable. RFA is cost-effective and allows early weight bearing with only activity modification for 3 months [49, 50]. Subcutaneous and intra-articular lesions as well as OOs close to critical structures are best treated with open curettage or en bloc resection with or without internal fixation. The risk to adjacent structures is too great to use RFA. Recurrence is most common in the 6 months following a procedure [51]. Risk is around 10 % with an indirect correlation with age [32]. Recurrence is treated in the same manner as the sentinel lesion.

14 Osteoblastoma

A rare osteoid producing tumor that is histologically indistinguishable from OO (Fig. 15). OB has a larger nidus ($\geq$2 cm) and clinical behavior that is more aggressive. It comprises 3 % of benign bone tumors, presents in the second and third decades, and is two times more common in men [34]. Long bone location is common. Symptoms are progressive swelling and achy pain. One-third of patients have lesions in the posterior elements of the spine, most often the lumbar and sacral regions [52]. Symptoms are neurologic compression and scoliosis. Pain is not worse at night and is not relieved by NSAIDs [13]. On average, patients have 2 years of symptoms before presenting for evaluation [53]. A geographic eccentric lesion with a narrow zone of transition, expansion, and variable ossified matrix is typically seen. Four to fourteen percent have a multifocal central nidus [53, 54]. Aggressive features such as cortical disruption, periosteal reaction, and soft tissue mass are possible. Matrix mineralization, cortical margin, and spinopelvic location are best visualized on CT. MRI detects bone marrow and soft tissue inflammation, but it does not obscure the lesion as in OO. Signal is low to intermediate on T1 and intermediate to high on T2 [55]. MRI shows lesion proximity to neural foramina and spinal cord [56]. Bone scan is active due to increased osteoblast activity. Secondary ABC occurs in approximately 15 % of lesions. Imaging shows aggressive changes when this occurs [57]. An osteoid nidus with rimming osteoblasts surrounded by a fibrovascular stroma with osteoclasts is the histologic

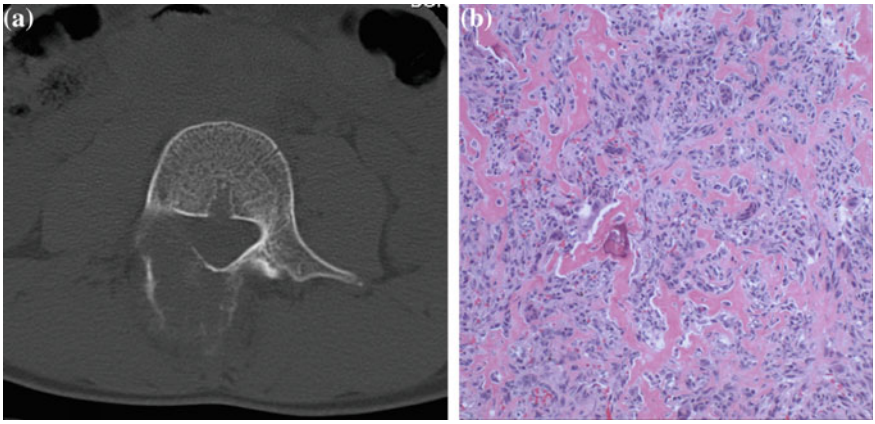

Fig. 15 Axial CT scan of the spine (**a**) and histology (**b**) of an Osteoblastoma of the posterior elements of the L4 lumbar vertebrae

appearance [36]. More aggressive lesions tend to have large epitheloid-like osteoblasts that are mitotically active [54, 55]. OBs do not have malignant or metastatic potential, but they are progressive and lead to pain, bone destruction, spine instability, and neural compression if untreated. Intralesional curettage and grafting with or without internal fixation for stability is the preferred treatment. Recurrent, refractory, or particularly aggressive lesions should be considered for en bloc resection. Recurrence risk is related to the adequacy of resection and is higher than OO at 10–24 % [52]. It is important to distinguish OB from low-grade osteosarcoma as both form osteoid and bone.

15 Unicameral Bone Cyst

UBCs are true cysts with unknown origins (Fig. 16). They occur more frequently in males and are diagnosed in the first two decades. Pathologic fracture and incidental finding are the most common presentations. Frequent locations include the proximal humerus and proximal femur in children [14]. Adults may have lesions in the calcaneus and ilium, which usually appear adjacent to the sacroiliac joint. Radiolucent central metaphyseal lesions with mild expansion and a narrow zone of transition characterize radiographs. UBCs often abut growth plates and move away with skeletal growth. A “fallen leaf” sign, where a fracture fragment falls to the dependent portion of the lesion, is seen in approximately 5 % of lesions [18, 19]. Loculations and pathologic fracture can best be seen on CT. MRI shows low T1 and high T2 signal with rim enhancement typical of a cyst [14]. A single layer of mesothelial cells comprises the cyst wall and is seen in conjunction with pressurized serous fluid on histology [13]. Osteoid may be seen when there is a pathologic fracture. UBCs tend to elongate with skeletal growth and then spontaneously fill-in at maturity. Most can be observed with pathologic fractures

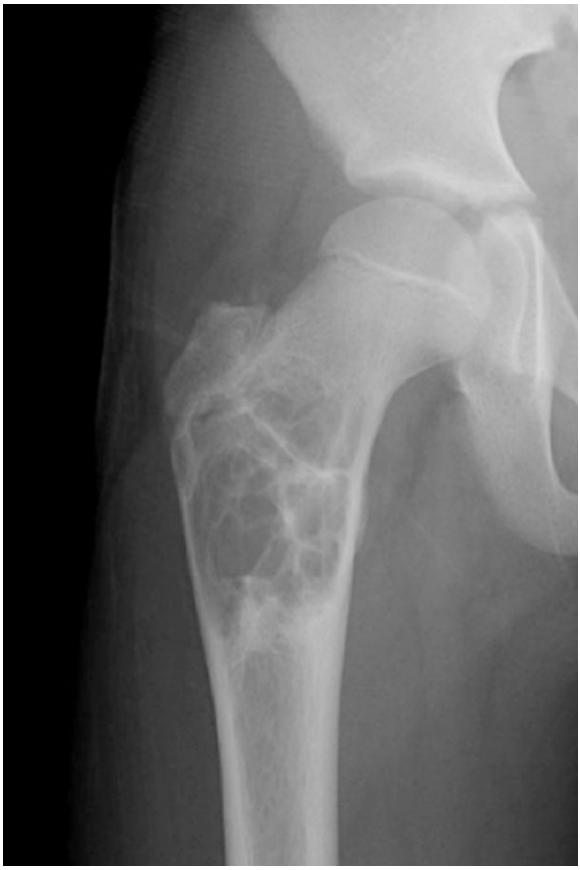

Fig. 16 Radiograph of a right proximal femur unicameral bone cyst

treated conservatively. Patients with large lesions at a young age or multiple fractures can be considered for treatment. Aspiration of the brown fluid for cytologic diagnosis, followed by injection of various substances can be done to try and stimulate healing and spontaneous filling. Common injected substances include steroids, bone marrow aspirate, and demineralized bone matrix (DBM). Multiple injections are usually needed. Venting is done during injection to prevent pressurization and embolization. Injections close to the physis can risk growth arrest and should be done with caution. Curettage and grafting with or without internal fixation is performed in older children and adolescents. These lesions are safe for an open procedure because they are further away from the physis and articular cartilage. Recurrence risk is 25–50 % with a greater likelihood associated with younger age [58]. UBCs in high-risk locations such as the femoral neck are treated with weight bearing and/or activity restrictions, aspiration and injection, or rarely, curettage with either placement of allograft cortical strut (younger patients) or internal fixation (postpubertal or >13 years old).

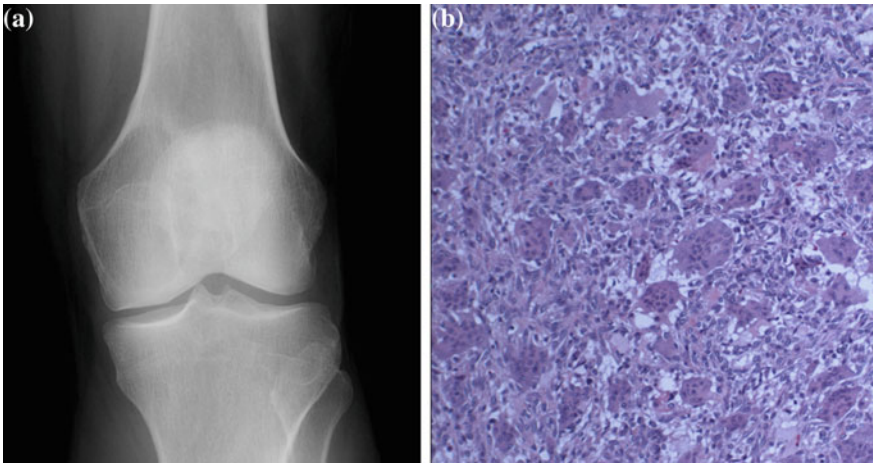

Fig. 17 Radiograph (**a**) and histology (**b**) of a lateral femoral condyle giant cell tumor

16 Giant Cell Tumor

GCTs are neoplasms of unknown origin (Fig. 17). They comprise 15–20 % of benign bone tumors [59]. Occurrence is usually in the third to fourth decades with a slight prevalence in females. Clustering has been identified with Paget's Disease, Chinese ancestry, and some families [13, 60–63]. Progressive pain and swelling are presenting symptoms. Pathologic fracture is associated in 30 % of patients [64, 65]. The distal femur, proximal tibia, and distal radius are the most common locations, followed by the sacrum, pelvis, ankle, and foot. GCT may be hormone responsive and worsen during pregnancy or with oral contraceptives [13]. Demonstrated as an eccentric radiolucent expansile mass in the epiphysis on X-ray, there is a narrow zone of transition that may be faint. Aggressive features such as cortical destruction, periosteal reaction, and bone loss are not uncommon. The cortical rim, remaining subchondral bone, and lack of internal matrix are best appreciated on CT. MRI may show a soft tissue component along with low to intermediate T1 and low T2 signal, which is secondary to high cellularity and hemosiderin [66, 67]. Lesions are vascular and show MRI enhancement [8]. PET activity is enhanced due to an elevated level of ATP-dependent proton pumps in the giant cells [68, 69]. Numerous multinucleated giant cells are seen among a bland mononuclear background with similar appearing nuclei on microscopic review [70]. GCT is a progressive, destructive tumor. Secondary ABC is common and can be responsible for sudden aggressive behavior. Treatment is intralesional with curettage and grafting/cementing with or without internal fixation. Around 3 % of GCTs metastasize to the lung [71]. All newly diagnosed patients should obtain chest imaging. Any metastatic foci are often indolent and are either observed or marginally excised via thoracotomy [72]. Progressive or numerous metastases warrant Imatinib (Novartis, East Hanover, NJ) or

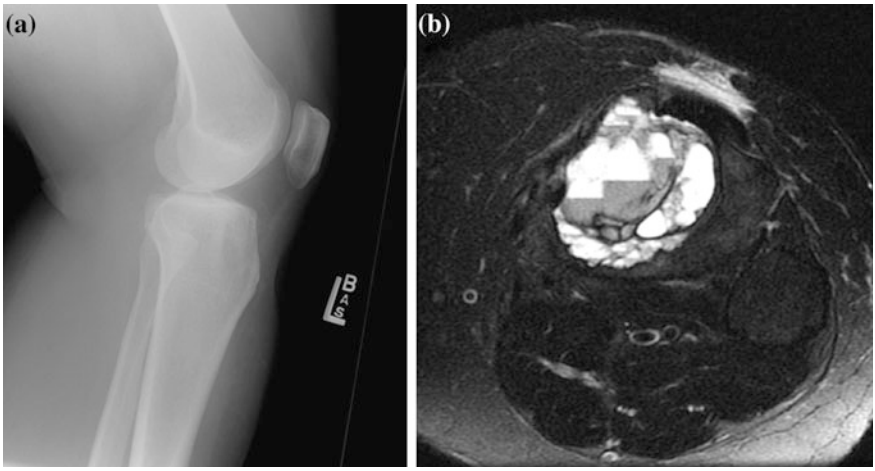

Fig. 18 Lateral radiograph (**a**) and T2 axial MRI (**b**) of a left proximal tibia aneurysmal bone cyst with characteristic fluid-fluid levels

chemotherapy, often with Adriamycin and Cisplatin [73]. Refractory, multiply recurrent, and particularly aggressive lesions may undergo en bloc excision. Inaccessible and difficult to treat areas such as the spine, skull base, pelvis, and sacrum in adults and adolescents have few options. Recently approved by the FDA, systemic treatment with monoclonal antibody to RANK ligand appears effective. Immature osteoblast-like cells in the GCT stroma lead to high expression of RANK ligand by the tumor. Blocking RANK ligand binding to the RANK receptor on monocytes prevents osteoclast-like giant cell activation and bone destruction [74]. Uncoupling osteoblast activation of osteoclasts removes bone as a source of calcium, putting patients on RANK ligand inhibitors at risk of hypocalcemia [75]. The safety of these medications, especially in the developing skeleton and with long-term use, is relatively unknown. Bisphosphonates can also be used. Zoledronic Acid (Novartis, East Hanover, NJ) is the most effective and works through the direct inhibition of osteoclasts [76]. Radiation, embolization, and RFA are other considerations infrequently used. Local recurrence rates are approximately 20 % after curettage. Most receive a second curettage, which works as well as primary curettage [77]. Patients need to be monitored with radiographs for lesion recurrence and pulmonary metastases, which develop an average of 3.8 years after initial diagnosis [73].

17 Aneurysmal Bone Cyst

ABCs have a controversial etiology (Fig. 18). Currently, they are thought to result from a translocation where a ubiquitin-specific protease becomes over-expressed and leads to activation of matrix metalloproteinases that remodel bone matrix and increase vascular endothelial growth factor (VEGF) [78]. Primary ABCs occur in

the first two decades and present with localized pain and swelling. On average, patients endure 6 months of pain before presenting to a physician [27]. In the spine, patients can present with nerve root or spinal cord impingement. Long bones are the most common site, followed by the pelvis and posterior elements of the spine [13]. The thoracolumbar region is most affected and 30–40 % of lesions extend multiple levels [27]. A radiolucent eccentric expansile lesion in the metaphysis is the typical radiographic appearance. The zone of transition is narrow. ABCs actively enlarge and a thin outer rim develops that can show signs of destruction and periosteal reaction, which is best seen on CT scan. No mineralized matrix is present. MRI demonstrates variable T1 and T2 signal due to internal blood products of different age and surrounding bone edema [79]. Reactive edema can be an indicator of aggression. The most characteristic finding is fluid-fluid levels, best seen on axial MRI. Internal septa enhance with contrast [8]. Secondary ABCs develop out of preexisting benign bone tumors, most commonly GCT, OB, and CB [14]. Spindle cell fibrous septae with numerous lining osteoclast-like giant cells around woven bone trabeculae and cavernous blood-filled spaces is the histologic appearance [80]. There is no endothelial lining and vessels are thin-walled [27]. Given the progressive nature of ABCs, their treatment is surgical. Accessible lesions receive intralesional treatment with curettage and grafting with or without internal fixation. Preoperative embolization is considered to minimize intraoperative blood loss. Aggressive and recurrent lesions as well as lesions in expendable bones should be considered for en bloc resection. Inaccessible lesions are treated with embolization or alcohol-based sclerotherapy. Recurrence is best detected with MRI and the risk is approximately 10–20 % with curettage. Repeating prior treatment is acceptable and effectiveness is equivalent. Most recurrences are in the 2 years following treatment [27]. It is important to differentiate these lesions from telangiectatic osteosarcomas.

18 Eosinophilic Granuloma

EOG is an inflammatory bone lesion from Langerhan Cell Histiocytosis (LCH), which is considered a disease of the reticuloendothelial system (Fig. 19). It presents in the first decade, more often in males, and usually as a solitary lesion, although it can be multifocal [81, 82]. Multifocal involvement occurs in one-third of spine lesions and is typically seen in younger patients [27]. Pain, restricted motion, and spine deformity are frequent presenting symptoms. Flat bones, long bones, and anterior elements of the spine are common locations. The thoracic region is often affected in the spine. An aggressive mixed density lesion with variable zone of transition and associated periosteal reaction with a central location in the vertebral body or long bone diaphysis is the classic radiographic appearance. Vertebral bodies can show asymmetric wedge collapse or symmetric flattening known as "vertebrae plane." This can lead to a kyphotic deformity [81, 83]. Disk spaces are maintained and soft tissue mass is absent. CT defines cortical anatomy and MRI is

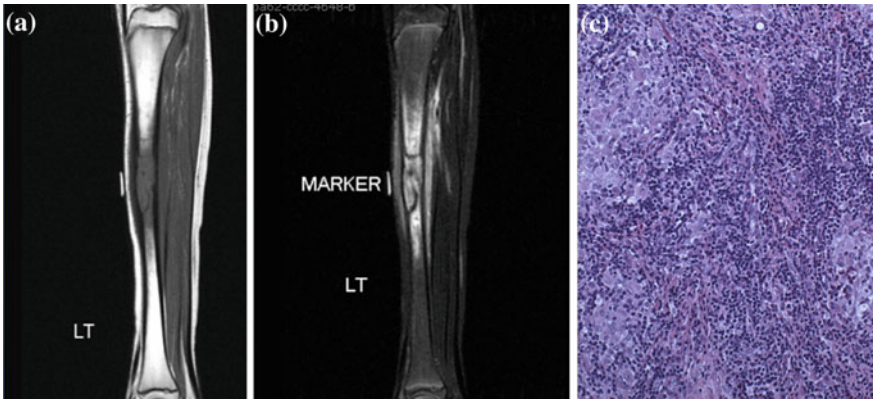

Fig. 19 T1 MRI (**a**), T2 MRI (**b**), and histology of Eosinophilic Granuloma

nonspecific low T1 and high T2 signal with contrast enhancement. A ring of new lamellar bone can often be seen on axial CT and MRI, giving a target sign. Bone scan demonstrates variable activity with EOG and therefore a skeletal survey is preferred to look for multifocal involvement. Punched out radiolucent lesions are often seen in the skull in systemic disease. Histology shows a mix of histiocytes, lymphocytes, eosinophils, and polymorphonuclear cells (PMNs). Histiocytes stain S100, CD1a, and CD68 positive and have a grooved nucleus with tennis racquet shaped organelles in the cytoplasm called "Birbeck granules," which are best seen under Electron Microscopy [27]. Cells are generally uniform and lack atypia. On imaging, EOG looks very similar to marrow cell tumors and infection. Blood work may show an elevated ESR and Ferritin, which can help with diagnosis. Biopsy, however, is usually performed. It is important to take cultures at the same time as biopsy. Isolated EOG lesions resolve spontaneously and only require symptom management, activity restriction, and observation with serial radiographs in limbs and MRI in the spine. With spinal deformity, bracing helps prevent progression. Some reconstitution of vertebral body height occurs with lesion resolution [27]. When refractory to bracing, surgery may be necessary to halt progression of deformity. Intralesional curettage is recommended for aggressive and impending fracture lesions. Internal fixation may be used to support bone as the disease runs its course. Multifocal EOG exists on its own or as part of a disease constellation. Multifocal EOG warrants a CT scan to look for visceral involvement and a referral to see a medical oncologist to consider low-dose chemotherapy and/or steroids to control disease until resolution. There are two disease constellations. Letterer-Siwe is associated with hepatosplenomegaly and anemia. It is seen in children less than 3 years old and universally fatal. Hand-Schuller-Christian Disease has dissemnated visceral involvement with exopthalmos and Diabetes Insipidus [27]. Medical management is indicated. Recurrence of EOG is rare in skeletally immature patients and more likely in adults [82, 83].

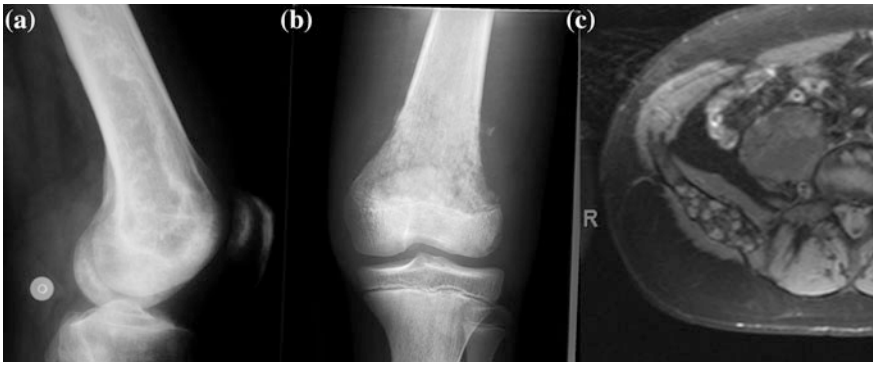

Fig. 20 Radiographs of a Bone Infarct (**a**) and osteomyelitis (**b**) in the distal femur. Axial T1 Fat-suppressed MRI of an osseous hemangioma (**c**) of the right ilium

19 Other Bone Lesions

Many processes create abnormality in bone and it is important to keep these in consideration when making a diagnosis (Fig. 20). An enostosis or bone island is a focus of dense lamellar bone with normal haversian canals [13]. It is often incidentally found on imaging. X-ray and CT show spiculated margins. MRI is low T1 and T2 signal with normal narrow and no surrounding edema [84]. Bone scan is cold. Observation is appropriate. Multiple lesions on both sides of a joint can be a benign autosomal dominant dysplasia called osteopoikilosis [13]. TUG lesion is a cortical irregularity at the medial posterior distal femur. This is an overuse injury in adolescents and only requires activity modification and observation. Intraosseous lipoma is mature fat in a cystic area of bone. The most common presentation is an incidental finding in a long bone metaphysis or calcaneus in a thirty to 50-year old [85]. MRI confirms the diagnosis by demonstrating signal consistent with fat on all sequences. Intraosseous ganglion cysts and subchondral cysts are subchondral radiolucent lesions with sclerotic margins with or without associated arthritis. Bone Infarct results from disrupted blood supply to an area of bone. There are many potential causes including fracture, dislocation, radiation, sickle cell disease, alcoholism, steroid use, and hyperlipidemia [86]. Radiographs show a serpiginous area that appears as "smoke rising from a chimney." MRI shows a characteristic mixed signal with infiltrative fat. Treatment of the lesion is observation. There is a very small chance of malignant transformation. Osseous hemangioma is usually an incidental finding in the metaphysis of long bones and in vertebral bodies of adults [13]. A striated radiographic appearance is seen in vertebral bodies. CT and MRI can show phleboliths and fat signal between vascular channels [56, 87]. Treatment is observation. Embolization is considered with refractory pain. Glomus tumors are rare focal hemangioma-like lesions that occur in the subungual region of the hand terminal phalanx. The distal phalanx frequently shows erosions [88]. Lesions are

very painful and sensitive to cold. Treatment is marginal excision. Osteomyelitis is bone infection. It presents with swelling, warmth, erythema, and fever. Children are more susceptible to acute infection due to metaphyseal venous pooling [85]. ESR, CRP, and blood cultures should be obtained and aspiration considered for culture. MRI shows dark marrow signal on T1 and bright marrow on T2. Enhancement can be seen on MRI and bone scan in areas of increased blood flow [85]. Localized chronic infection is known as a Brodie's abscess. A central area of necrotic infected bone known as the sequestrum is surrounded by sclerotic host bone known as an involucrum. Acute osteomyelitis can be treated with antibiotics. Chronic osteomyelitis or infection with necrosis, purulence, or sequestrum needs debridement and irrigation in addition to antibiotics.

19.1 Treatment

section will discuss treatment in greater detail. Lesions that appear latent are observed. Serial imaging helps to document any tumor progression. This is typically done with radiographs. Areas of complex anatomy such as the acetabulum, pelvis, sacrum, spine, hands, and feet may require advanced imaging with CT or MRI. After initial patient evaluation, imaging is generally repeated at 3, 6 months, and then every 12 months. Children and adolescents should be followed until shortly after skeletal maturity. Adults need to be followed for a minimum of one to 2 years. Any concern in lesion progression in either population should prompt earlier follow-up, advanced imaging, or biopsy.

Active and aggressive lesions are progressive and treatment is necessary to limit morbidity. When pathologic fracture is present, it is best to wait 6-8 weeks to allow fracture healing. This establishes a continuous bone cavity and helps reduce the likelihood of recurrence [89]. In most cases, an open biopsy is performed first through a limited incision. Staying within one anatomic compartment is important because tumor contaminates the dissection area. Specimen should be sent for intraoperative frozen section. If a benign diagnosis is confirmed, treatment continues under the same anesthetic. Any uncertainty of the diagnosis should end the procedure at biopsy and any further surgical action waits until the final diagnosis is confirmed. Diagnostic yield is better with open biopsy compared to percutaneous techniques for benign bone lesions. Frozen section can determine adequacy of tissue sampling even if a diagnosis cannot be made [8]. Definitive treatment of active and aggressive lesions is usually intralesional with open curettage. The goal is removal of all neoplastic tissue. Full exposure of the cavity with a large cortical window facilitates visualization of the tumor and allows access to all areas with a curette. High-speed burr (HSB) is used as a mechanical curette in order to extend the resection margin and remove residual microscopic tumor. Use of fluoroscopy with the burr helps prevent excessive bone removal and minimizes postoperative fracture risk. A probe is beneficial to assure that all septae and trabeculae have been violated in multicystic lesions.

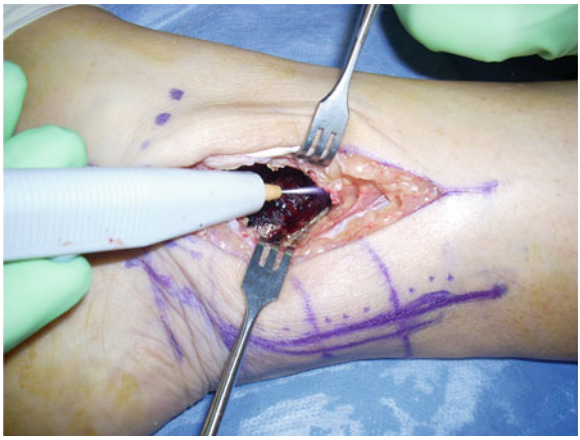

Fig. 21 Adjuvant use of the argon beam coagulator on the wall of a benign bone lesion in the distal tibia

Recurrence risk is associated with the extent of lesion resection and the technical quality of the surgery. Curettage alone is associated with a high recurrence rate of 30–50 % [90–93]. This can be diminished with use of an adjuvant treatment to 10–20 % [94–96]. Many adjuvants are available and preference is institutional. They have all demonstrated effectiveness and the ability to reduce recurrence rates with similar functional outcomes and complications [92, 94–98]. Liquid nitrogen or cryosurgery requires an intact bone cavity and works through repetitive fast freeze/spontaneous thaw cycles. Each cycle decreases tissue vascularity and increases thermal conductivity leading to the production of intracellular ice crystals, which produce mechanical cell damage [94, 99–101]. Osteonecrosis results and creeping substitution begins at 7 days. A 7–12 mm rim of necrosis is achieved [102]. Fracture risk is high and requires protected weight bearing for 3 months postoperatively. Phenol is a weak acid that directly denatures proteins and damages DNA. It is often applied to the walls of intact bone cavities with a cotton tip applicator. Dissolved in alcohol and typically used in an 85 % concentration, phenol is applied for one minute and then neutralized with sodium bicarbonate [100, 103]. It achieves a 0.5 mm rim of necrosis and is ineffective against cartilage [104]. Spill is the main risk with resultant necrosis of normal tissue [105]. Argon beam coagulation is a spray of inert argon gas that coagulates proteins and desiccates tissue [97, 106] (Fig. 21). It can be applied to incomplete bone cavities. Depth of necrosis depends upon the power of the beam and length of time it is applied. Application of 100 Watts for 5 s gives an average necrotic rim of 5.5 mm [107, 108]. Primary risk is fracture and warrants restriction of postoperative weight bearing and/or activities [89].

Created bone defects are generally large and require some filling substance to offer temporary structural support. Polymethylmethacrylate (PMMA) offers immediate long-term support. It is best used in adults and in areas adjacent to subchondral bone. There may be a secondary adjuvant effect from the heat of polymerization and the cement monomers themselves that have a direct cytotoxic effect on tumor cells. This creates a 1–2 mm fibroblastic reaction around the bony

rim [102]. Further, PMMA creates a characteristic radiographic appearance that makes it easy to detect recurrence [100] and also has elution qualities that allow incorporation of antibiotics or bisphosphonates into the filler. Drawbacks are lack of biologic incorporation and damage to surrounding structures from heat necrosis [109]. Placing demineralized bone putty or gel foam between subchondral bone and PMMA may protect articular cartilage. Other fillers are more biologic; they serve as a mixture of temporary support and scaffold for host bone to incorporate. This type of filler is preferred in children and younger patients. Cancellous bone graft is frequently used although its structural support is minimal. Autograft is osteoinductive, osteoconductive, and safe, but harvest contributes donor site morbidity and supply is limited. Allograft is osteoconductive but does not have bone promoting biologic factors, although mixture with DBM may add some osteoinductive properties. There is no donor site morbidity with allograft. However, this is exchanged for the risk of disease transmission from cadaver to recipient. Synthetic fillers are additional options for osteoconduction. Current preference is use of a composite containing calcium sulfate, calcium phosphate, and β-tricalcium phosphate. The different resorption properties balance structural support with porosity to allow host vascular ingrowth and osteoblast recruitment [110]. Use in lower extremity lesions has demonstrated enough bony consolidation after an average of 7.3 weeks to allow full weight bearing and unrestricted activities [111]. Identification of lesion recurrence can be challenging with composite grafts and they need to be removed during infection [111].

En bloc resection is excessive for the majority of benign bone tumors. These tumors do not metastasize and the main concern is local recurrence and local morbidity. While GCT of bone carries a low risk of metastatic disease, the clinical behavior of these metastases does not warrant more aggressive primary treatment. Contemporary intralesional management adequately minimizes recurrence in benign bone tumors and serves as first-line treatment in accessible lesions. Resection is a consideration in a few circumstances. Aggressive lesions in expendable bones, multiply recurrent, and recalcitrant lesions producing substantial local morbidity may justify the risk of a more substantial surgery.

Percutaneous treatment for benign bone tumors, with one exception, is considered for inaccessible lesions or patients medically unfit for surgery. RFA for osteoid osteoma is considered equivalent to open curettage and used first-line in appropriate locations. The technique is safe and also serves as a secondary option in other benign bone lesions. RFA is performed under anesthesia because bone drilling and placement of a biopsy needle into the lesion is necessary [32]. Further, minimal movement aids the accuracy and limits radiation exposure with CT guidance. A monopolar electrode is centrally placed into the tumor and a temperature of around 90 °C is maintained for 5–6 min [112]. Complications are low, recovery is quick, and clinical success with one treatment is approximately 91 % [49]. Care must be exercised in subcutaneous areas and around neurovascular structures. Sclerosing therapy is another percutaneous option and has demonstrated clinical success, most notably in ABCs. The procedure is outpatient and done

under anesthesia with fluoroscopic guidance [113]. Several injections are usually needed to successfully thrombose the tumor blood supply. Complications are not uncommon and include cutaneous fistula, local inflammation, hypopigmentation, abscess, and fracture [114]. External beam radiotherapy (EBRT) can also be effective against inaccessible aggressive lesions. The photon energy induces DNA damage. Multiple cycles are given over several weeks. Effectiveness is 84 % with >50 Gy of radiation [115]. Risks include local inflammation, growth arrest, tissue scarring and necrosis, fracture, and secondary sarcoma formation.

After treatment, lesions need to be monitored for local recurrence. Length of surveillance can vary but should take place for at least 5 years. One approach is to monitor with clinical exam and imaging every 3 months for the first postoperative year, every 4 months for the second postoperative year, every 6 months for the third postoperative year, and then annually for the duration of follow-up. Any clinical or radiographic concern should warrant earlier follow-up, advanced imaging, or biopsy. GCT also needs chest monitoring during follow-up.

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